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EXPERIMENTAL INVESTIGATION, OPTIMIZATION AND MODELING OF CARBON FIBRE GRAPHITE/EPOXY LAMINATES WITH THE HELP OF ABRASIVE WATER JET MACHINE

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ABSTRACT

In the present overall innovation centric development, a large measure of work is completed on machining of Carbon fiber Graphite/Epoxy which covers utilization of the Abrasive Water Jet machine (AWJM). AWJM is one of the non-standard machining processes that has been comprehensively used for machining of Carbon fiber Graphite/Epoxy overlays. It is used for cutting and slicing hard-to-cut materials. This procedure is less delicate to material properties and consequently does not cause babble, irrelevant thermal impact, negligible weight on the workpiece and high machining adaptability. The utilization of composite materials becomes noticeable in the present current innovative applications. It has novel attributes, for example, high modulus to weight proportion, high solidness to weight proportion, high weakness continuance limit, low thickness and incredibly savvy. AWJM procedure gives a solitary apparatus that is reasonable for machining wide scope of composite materials. From the assessed composition, it has been found that not a lot of research attempts are contributed to the examination on AWJM of Carbon Fiber Reinforced Polymer (CFRP). The objective of this paper is to explore the impact of procedure parameters, to be specific Abrasive Mass Flow Rate (AMFR), Stand-Off Distance (SOD), Kerf qualities, cross speed, Depth of Cut (DOC) on surface unpleasantness, Material Removal Rate (MRR) of CFRP by utilizing exploratory examination, optimization alongside modeling and simulation methods utilized in AWJM.

KEYWORDS: Delamination, Abrasive Water Jet Machining, Optimization, Modeling & Simulation

Original Article

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INTRODUCTION

AWJM is broadly utilized in different modern applications, for example, slicing hard-to-cut materials, boring and pocket processing in composite parts, cutting different materials in textile and leather enterprises and so on. This innovation is valuable for mechanical applications since it has focal points, for example, less touchy to material properties, no babble, no warm impacts, negligible weights on the workpiece and high machining versatility and adaptability, additionally, AWJM produces surfaces of worthy completion and high integrity. Cutting and machining rate of AWJM is higher than ordinary machining forms [1]. In AWJM process, (Figure 1) the undesirable material of workpiece is evacuated by the consolidated activity of rapid water and abrasive particles. The rapid flow of water moves the motor vitality to the abrasive particles and the blend (water and abrasives) encroaches on the workpiece material. The exhibition of AWJM procedure is subject to the disintegration of material by the pressurized water-abrasive blend and mechanical properties of workpiece material alongside different procedure parameters [2].

It is the most suitable material removal process since it requires no cutting fluids and creates no exhaust or waste when contrasted with conventional machining and other non-customary machining forms. Composites have picked up the prominent place in worldwide assembling situation particularly where refined items are required which must be light and solid to withstand different loads in a troublesome domain. Composites have heterogeneous (non-homogeneous) nature and they comprise of solid filaments joined into nearly milder lattice. Thus, conventional machining procedures are not appropriate for machining of these materials. The primary points of interest of composites are their high quality and solidness, joined with low thickness.

Machinability of Fiber Reinforced Polymers (FRP) by conventional method is poor as a result of intemperate tool wear, delamination, and unreasonable cutting powers and cutting temperatures. Better machinability is accomplished by limiting apparatus wear and delamination while keeping up high creation rates. Considering the way that devices wear increments with an expansion in cutting velocity and feed rate (e.g. an expansion under way rate), it is routinely problematic in machining composites through traditional methods.

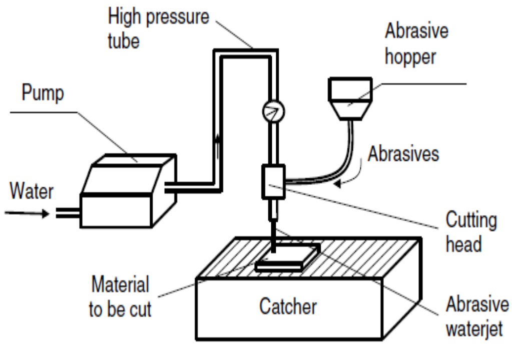

Figure 1: Abrasive Water Jet Machining Process [2].

Usage of composites in corporate aviation, transportation, development, marine merchandise, outdoor supplies, and all the more than of late foundation, with development and transportation being the biggest and consequently AWJM technology has received impressive consideration from these ventures. As far as, AWJM of composites is concerned, the sort of abrasives, hydraulic pressure, and cross-rate are increasingly critical procedure parameters when contrasted with different procedure parameters, for example, SOD, AMFR, and cutting direction to accomplish great surface completion. But in the cutting of composites particularly laminated composites, delamination is significant composite imperfection. While AWJM of composites, abrasive Water Jet (AWJ) makes shock wave sway on the material on account of which break tips are created in the workpiece material at the starting cutting stage. Presently, the pressurized AWJ enters into the break tips which will in general water-wedging and abrasive insertion [2].

LITERATURE REVIEW

The endeavors connected by overall specialists in the zone of AWJM of composites are extensively characterized into three classifications – cutting execution of AWJM process, optimization of procedure parameters and modeling of AWJM process.

Cutting Execution of AWJM Process

A large portion of the analysts have researched the cutting execution of AWJM of composites, for example, surface

harshness, kerf properties, material removal rate, and so on. For instance, Shanmugan et al. [2] have done the relative investigation of jetting advancements and lesser machining procedures. The investigation was focused on machining of composite materials like epoxy graphite texture and fiber reinforced plastic materials which are utilized in aviation enterprises. Machining of composites was completed with customary machining, however contrasted and flowing and laser advancements. **Ramulu and Arola [3] did a trial examination to decide the impact of cutting parameters superficially unpleasantness and kerf decrease of a rough water flow machined graphite/epoxy cover.** A trial examination on AWJM for machinability and kerf qualities of polymer lattice composite sheets was done by Wang [4]. In this exploratory work, major and minor to customizable procedure parameters were viewed as which may prompt ill-advised outcomes. A trial deal with cutting of GFRP composite materials with AWJM with head wavering was done by Lemma et al. [5]. The entire examination was focused on cutting head swaying however; at last, the enhancements in surface quality were discovered a lot higher with increment in the point of wavering than with increment in recurrence of wavering. Arola and Williams [6] analyzed impact of machined surface on the weariness quality of a Graphite/Bismaleimide (Gr/Bmi) overlay. The examination was done because of opening quality on the mechanical conduct of fiber strengthened overlays was performed by Arola and Mccain [7]. The work has constrained applications and furthermore, analysts have utilized both traditional as well as non-conventional procedures to machine the example. Wang and Liu [8] completed trial examination on different cutting execution estimates, for example, kerf decrease and DOC in profile cutting of alumina earthenware production by abrasive water flow. Azmir and Ahsan [9] directed trial examination to evaluate the impact of AWJM process parameters on surface harshness of GFRP composites utilizing Taguchi's method and investigation of change was to deal with improving process parameters for viable machining. However, the specialists have made their decisions just based on surface unpleasantness accomplished while some significant estimates; for example, material expulsion rate and kerf geometry properties were not considered. **Prisco and D'Onofrio [10] completed a computational fluid element's simulation of the arrangement and release procedure of an air-water flow in an abrasive water jet head.** The investigation on surface harshness and kerf decrease proportion attributes of AWJM for glass/epoxy composite cover was completed by Azmir and Ahsan [11]. The effects of machining parameters on surface brutality and kerf decline extent were analyzed using Taguchi's method of tests and examination of distinction. In any case, the cutting execution is evaluated unmistakably dependent on surface brutality achieved and kerf reduction extent made. Sadat [12] utilized ring molded test tests having outside and inside breadths of 65 mm and 52.5 mm individually of aluminum metal network composite material. A near investigation of different procedures for cutting cotton fiber polyester composite by keeping up unidirectional fortification was completed by Sheik and Jain [13]. Srinivas and Ramesh Babu [14] performed set of concentrates on aluminum-silicon carbide particulate metal lattice composites handled with abrasive water jet. But the scope of procedure parameters changed in this investigation is exceptionally little.

Patel and Shaikh [15] assessed the exhibition of AWJM of CRP through examination on the impact of flow effect edge on kerf attributes. Alberdi et al. [16] examined the machining of two unique composites each having various thicknesses to research the machinability file. Nedelcu et al. [17] completed a brief examination on composites' machining (regular and non-customary machining). The exploration work from the commencement to the improvement of AWJM inside the previous decade is checked on by Korat and Acharya [18]. Mayuet P.F. et al. [19] explored inward delamination of CFRP tests by utilizing Scanning Optical Microscope (SOM) and Scanning Electron Microscope (SEM). In this work, they proposed that SOM and SEM can recognize the instrument of development of delamination. Dittrich et al. [20] investigated AWJM of Al_2O_3 ceramics. Effect of process parameters on MRR, DOC and harshness was studied. It was

observed that for maximum erosion rate, low cross rate and high impact angle are significant. Mohammad et al. [21] investigated erosion mechanism and erosion rate in AWJM of borosilicate glass. Erosion mechanism found to be major material removal mechanism for brittle materials. Impact angle was found to be directly proportional to erosion rate.

Optimization of AWJM Process

For better execution of AWJM of composites, determination of legitimate procedure parameters is extremely important and along these lines, a few analysts have upgraded the procedure parameters of AWJM process. Geiger et al. [22] proposed a fluffy rationale hypothesis to develop a learning base for the water flow cutting of composite materials. For the fundamental examinations, composite material made of aluminum was utilized. They additionally built up a specialist framework as per the given structure parameters. The master framework decides the ideal cutting rate for the ideal cutting shape.

Azmir et al. [23] completed exploratory examination to survey the impact of AWJM process parameters on surface unpleasantness and kerf decrease proportion of Aramid Fiber strengthened Plastics (AFRP) composite. They [24] likewise tried to upgrade the AWJM procedure parameters with numerous exhibition qualities dependent on the symmetrical cluster with the dim social examination. In this examination work, AWJM of Kevler composite cover was performed. During machining, four procedure parameters specifically water powered weight, AMFR, stand-off separation and cross rate were considered. The improvement of these four parameters with thought of different execution attributes was completed. Shaikh and Ambardekar [25] researched the effects of system parameters, for instance, grating water weight; remain off division and cross rate on the significance of cut in unpleasant water stream cutting of metal-polymer-metal overlay. In perspective on examination of contrast, it was found that grating water stream weight and traverse remain off partition. Later on, a judicious model was made using backslide examination system. Bose P. et al [26] inquired about the effect of standoff expel, water weight, cross rate and AMFR on surface repulsiveness. They took a gander at and affirm the result by using ANOVA and Regression examination.

Modelling of AWJM Process

For the expectation of a portion of the significant factors in AWJM of composites, for example, delamination, depth of jet entrance, kerf properties and so forth a few specialists have created different models. For instance, Shanmugan et al. [2] completed test examination to investigate the delamination instrument in graphite/epoxy composites under AWJM. A semi-systematic model dependent on vitality preservation to anticipate the most extreme delamination length was created. In AWJM of Al_2O_3 and SiC ceramics, Hocheng and Chang [27] explored the mechanism and efficacy of MRR, achievable DOC, kerf shape and surface harshness. It was observed that particle speed is major affecting parameter to Material Removal Rate (MRR). MRR is affected by water pressure, AMFR, and mesh size of abrasive as shown in figure 2. Kerf decrease proportion increments with high cross rate and low water weight. Surface cruelty is influenced by cross rate, grating lattice size and rough stream rate. It was discovered that the impact of mesh size decreases, if the cross frequency becomes so big that the striation is severe. Water pressure, cross rate, and AMFR were found to be the most influencing parameters on the achievable DOC. If the cross rate is too high or the pressure is too low, the material cannot be cut through.

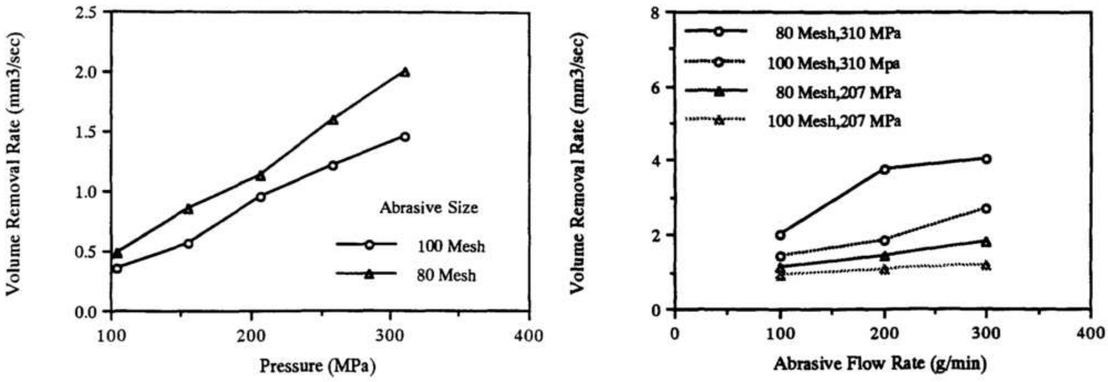

Figure 2: Causes of Water Pressure and AFR on MRR [19].

Cheng [28] built up an expository way to deal with concentrate the delamination during boring through water jet penetration. This model predicts the most ideal water jet weight for zero delamination as an element of opening depth and material parameters. Great understanding was accomplished with information received from water jet penetration of graphite epoxy overlay. Wang [29] researched the cutting execution and disintegration process in AWJM of polymer network composites. A scientific model was created for the complete DOC and checked together with observational models for the other kerf geometrical highlights.

Gudimetla et al. [30] investigated material removal mechanism and kerf characteristics in AWJM of alumina ceramic. It was noted that the most pronounced type of sub-surface harm for low cutting speeds was a type of ring fracture followed by plastic flow and sub-surface deformation. Due to the melting of abrasive particles, pitting was noted at low velocity. The dominant models of failure are high speed micro cracking and intergranular fracture. The increase in cross rate forms steps on the surface, due to jet instability, deflection, and rebounding of abrasive particle. High AMFR was suggested for minimum striation effect. Jet forward impact angle has been noted to be directly proportional to the complete DOC. Deam et al. [31] suggested a model for predicting cut profile status in contemporary slicing processes and associated with AWJM. Two renditions of this model were created. The model predicts a consistent span of ebb and flow for the cut profile; however this is finished with jet point not exactly around 600.

Ramulu et al. [32] surveyed the machining qualities as far as delamination and opening deformities. A deliberate investigation of the parametric impacts adding to the surface quality and harm actuated in cutting, penetrating of CFRP and half composites utilizing water flow and abrasive water jet advances was led. Cojbasic Z. et al. [33] proposed a model to anticipate surface unpleasantness by outrageous learning machine developed with AWJM. They created ELM model has many engaging and wonderful highlights which make it discernable from customary well known inclinations based learning calculations for feed forward neural systems.

Comments on Literature Review

The work done by overall scientists in zone of cutting execution, improvement and demonstrating of AWJM procedure of composites is outlined separately in table 1, 2 and 3. For the most recent four decades, AWJM procedure has been being utilized to machine and cut composites. Research in the course of the most recent two decades here demonstrated some improvement in the utilization of AWJM system as a cutting device for machining and cutting of composites. A large portion of the scientists have connected their endeavors to explore cutting execution of AWJM of composites through the cutting execution estimates, for example, surface completion, kerf properties, material expulsion rate, and so forth.

Analysts likewise worked and examined the impact of different procedure parameters on surface harshness, kerf properties and material removal rate. Be that as it may, not many scientists have connected endeavors to examine material expulsion rate in AWJM of composites. Despite the fact that AWJM is broadly utilized in the machining of composites, exceptionally less work has been found on the flow lining of AWJM process parameters for viable utilization of AWJM procedure. Hardly any analysts dealt with advancement of procedure parameters. In any case, they flow lined couple (a couple of) process parameters of AWJM. It is likewise discovered that less research endeavors have been connected in demonstrating of AWJM of composites. Scarcely, any specialists have effectively attempted to create prescient models for delamination, depth of jet entrance and DOC. Further, less exertion has been connected to examine AWJM of carbon fiber and epoxy resin composites. Hence, there is future extent of applying research endeavors in these recognized zones.

Table 1: Summary of Literature on Cutting Execution of AWJM

Researcher (s)	Investigation	Material	Scope of Further Work
Wang (1999)	Machinability and kerf characteristics	Polymer matrix composite	Investigation on all process parameters
Lemma et al. (2002)	Comparative oscillation research and ordinary slicing (without oscillation)	GFRP	Investigation on cutting head oscillation with impact angle
Azmir and Ahsan (2008)	Process parameter influences surface harshness	GFRP	Investigation on MRR and kerf properties
Azmir and Ahsan (2009)	Surface harshness and kerf taper ratio characteristics	GFRP	Consideration of MRR as cutting Execution measure
Srinivasan et al. (2012)	Effects of cutting velocity, feed and DOC on surface rigidity and cutting strength	Homogenized Al metal matrix composite	Must include materials other than MMCs
Sheikh and Jain (2012)	Comparative study of various processes	CFRP	Other nontraditional processes should be considered for comparison
Srinivas and Ramesh Babu (2012)	Penetration Ability	Al_2O_3 and SiC Metal Matrix Composites	Range of varied process parameters must be increased
Dittrich et al. (2014)	MRR, DOC and harshness	Al_2O_3	Kerf chartacteristics like striation angle
Mohammad et al. (2015)	Erosion mechanism and erosion rate	Borosilicate glass	Influence parameters on kerf and surface quality
Mayuet P.F. et al. (2015)	SOM/SEM based characterization of internal delamination	CFRP	Investigation on SR, MRR and kerf properties

Table 2: Summary of Literature on Optimization of Process Parameters

Researcher (s)	Investigation	Material	Scope of Further Work
Geiger et al. (2003)	Cutting speed	Light weight composites of aluminium	Parameters must be optimized for heavy composites also
Azmir et al. (2007)	Cross rate	Aramid fibre reinforced plastics	Impact angle should also be considered
Shaikh and Ambardekar (2013)	Water jet pressure and cross rate	Metal polymer metal laminate	SOD and impact angle must be considered
Bose Pratik. et al. (2016)	Surface harshness	GFRP	MRR and Kerf Characteristics must be considered
Dhanawade Ajit. et al. (2016)	Surface harshness	CFRP	Material Removal Rate and Kerf Characteristics must be considered

Table 3: Summary of Literature on Modeling of Process

Researcher (s)	Investigation	Material	Scope of Further Work
Hocheng and Chang (1994)	Mechanism of material removal, Kerf quality	Al_2O_3 and SiC	Model for DOC is required
Wang (1999)	DOC	Polymer matrix composite materials	MRR must be considered in the study
Gudimetla et al. (2002)	Mechanism of material removal and features of the kerf	Al_2O_3	Model for cutting model is required
Deam et al. (2004)	To foretell the shape of the cut profile	--	Impact angle range must be increased above 600
Shanmugam et al. (2008)	Kerf taper compensation technique	Al_2O_3	Application of model on other ceramic material is required
Cojbasic et al. (2016)	To predict surface harshness	--	Kerf Characteristics should be considered in the study.
Wibowo A. (2018)	To predict surface harshness	--	Kerf Characteristics should be considered in the study.

CONCLUSIONS

Survey of the open writing in the locale of AWJM of composites reveals that this technique is commonly used in machine composites. By cutting execution gages, for example, kerf characteristics and surface harshness, most officials have researched the cutting execution of AWJM of composites. Similar examinations have been done to think about the effect of various methodology parameters, for instance, weight, traverse rate, standoff distance, AMFR, etc. on execution gauges, surface roughness, and kerf properties. Attempts have been made to examine the delamination that occurred in composites and streamlining of technique parameters for least delamination, essentially in epoxy sap composites. Not many experts have given their undertakings on examination of showing, multiplication and cutting execution through surface and kerf characteristics of AWJM for CRPF. In AWJM of CRPF, therefore, there will be future increase in examination due to methodology parameters on surface characteristics and kerf characteristics.

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